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CASTOR THTR/AVR Containment Review

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LLNL-TR-813332

Document Review Report

for review of the documents

Containment Analysis for the Type B(U)F Package Transport and Storage Cask CASTOR® THTR/AVR,
GNS B 325/2018, Revision 1, June 26, 2020.

and

Test Specification Cask Structural Component – Leak Tightness Test Helium Leak-Tightness Test Procedure – CASTOR® THTR/AVR,
PV 360/82, Revision 3, June 24, 2020.

Docket Number: 17-43-9601

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by members of the

Lawrence Livermore National Laboratory Radioactive Material Packaging and Transportation Safety Group:

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1.0 Introduction

The Lawrence Livermore National Laboratory (LLNL) Radioactive Material Packaging and Transportation Review Team (herein referred to as 'LLNL Staff') was tasked with the technical review and confirmatory analysis of the containment analysis and corresponding leakage test implementation procedure for the CASTOR® THTR/AVR radioactive material transportation package with the AVR contents.

The CASTOR® THTR/AVR Type B(U)F package (i.e., cask) is designed to accommodate radioactive material from the thorium high temperature reactor THTR-300 and the high temperature reactor of the Arbeitsgemeinschaft Versuchsreaktor GmbH (AVR) type. The containment analysis document under review is entitled *Containment Analysis for the Type B(U)F Package Transport and Storage Cask CASTOR® THTR/AVR,* GNS B 325/2018, Revision 1 and is dated June 26, 2020.[1] This document includes a containment analysis for the CASTOR® THTR/AVR package with the approved AVR inventory (i.e., Item 3 of the Authorized Radioactive Contents of the German Approval Certificate D/4214/B(U)F-96, Revision 11).[2] The approved AVR inventory consists of up to 1900 fuel elements (FE) from the AVR reactor in each packaging.

The containment analysis in GNS B 325/2018 Revision 1 develops volumetric leakage test acceptance criteria from the regulatory allowable radioactive release rates in Title 10 of the United States Code of Federal Regulations, Part 71.[3] The implementing procedure to demonstrate the leakage test criteria developed in the CASTOR® THTR/AVR containment analysis is entitled *Test Specification Cask Structural Component – Leak Tightness Test Helium Leak-tightness Test Procedure – CASTOR® THTR/AVR*, PV 360/82, Revision 3, June 24, 2020.[4]

In the containment analysis, allowable radioactive material activity release rates are determined for Normal Conditions of Transport (NCT) and Hypothetical Accident Conditions (HAC) based on the containment criteria in the applicable United States Regulations (i.e., 10 CFR Part 71). The analysis follows the methods outlined in U.S. Nuclear Regulatory Commission NUREG/CR-6487[5] and NUREG-1617,[6] where the releasable source terms and the corresponding allowable leakage rates are determined using the approaches and transport equations in ANSI N14.5 -2014.[7]

2.0 Review Approach

The review approach included examining the subject documents, the references in the subject documents, as well as performing independent confirmatory calculations. The information in the documents was compared to regulatory requirements and to the guidance in consensus standards.

3.0 Review Results

The following are the results of the review and confirmatory analysis of the document *Containment Analysis for the Type B(U)F Package Transport and Storage Cask CASTOR® THTR/AVR,* GNS B 325/2018, Revision 1, June 26, 2020.

Section 1. Introduction and Summary
This section stipulates that the CASTOR THTR/AVR Type B(U) package (i.e., 'the cask') is designed to accommodate material from the thorium high temperature reactor THTR-300 and the high temperature reactor of the AVR type. The report contents are described as a containment analysis for the AVR inventories (i.e., Item 3 of the Authorized Radioactive Contents of the German Approval Certificate D/4214/B(U)F-96, Revision 11). The approved AVR content includes up to 1900 fuel elements in each loading. The LLNL Staff can confirm that the calculations throughout the document utilize the characteristics of the authorized AVR inventory (i.e., Item 3 in the German Approval Certificate D/4214/B(U)F-96, Revision 11) and that an inventory loading consisting of 1900 fuel elements was considered in the calculations.

The Introduction and Summary section also describe that the demonstration of the compliance of the containment system follows the stipulations in 10 CFR 71 under consideration of the approaches described in NUREG/CR-6487 and NUREG-1617. The approach described includes determining the allowable activity release rates, for both Normal Condition of Transport (NCT) and Hypothetical Accident Condition (HAC), based on the containment criteria defined in NUREG/CR-6487 along with the corresponding boundary conditions and AVR inventory characteristics. Analytical calculations by means of the Knudsen equation with a one-capillary model were performed to convert the allowable release rates at transport condition into reference air leakage rates.

The LLNL Staff confirmed the approval of the AVR contents and loading in the CASTOR® THTR/AVR package as described in the German Approval Certificate. Also, it was confirmed that the calculational approach in the document was consistent with NUREG/CR-6487 and correspondently ANSI N14.5. The Introduction and Summary section concludes with the stipulation of the CASTOR® THTR/AVR package containment system with the AVR content has a reference air leakage rate of 0.3 $ref{\cdot}cm^3/s$. This reference air leakage rate was confirmed by LLNL Staff, as described below.

Section 2. Containment Criteria
This section lists the allowable release limits in terms of A_2 for Normal Conditions of Transport (NCT) and Hypothetical Accident Conditions (HAC) from 10 CFR 71. Also shown is the equation for calculation of an effective A_2 for a mixture of radionuclides from 10 CFR 71.

The LLNL Staff confirms that the equations shown for allowable release limits and the calculation of effective A_2 for a mixture of nuclides are appropriate.

Section 3. Boundary Conditions
This section compiles the boundary conditions for the containment analysis. It is stated that 'The general containment requirements for the cask - e. g. appropriate closure of the cask and prevention of unintended opening, no dependence of the containment on filters or mechanical cooling systems, acceptable component temperatures, appropriate size of gasket grooves and material compatibility of cask and inventory - are demonstrated via the document GNB B *078/2004,* Revision 0.[8] This was confirmed by the LLNL Staff.

Section 3.1. Containment System

This section describes the containment boundaries for the CASTOR® THTH/AVR package. From the size of the metal O-rings employed, a leakage hole length can be estimated as the diameter of the metal O-rings in the primary/secondary lid (3.5 mm) or the diameter of the metal O-rings in the protection caps or the blind flanges in the primary/secondary lid (2 mm).

The LLNL Staff concurs with the description of the containment boundary of the CASTOR® THTR/AVR package and the determination of the leakage hole length across the metal O-rings.

Section 3.2 Package Contents

This section describes that an admissible content loading for the CASTOR® THTR/AVR cask is the irradiated and undamaged fuel elements (FE) and operating elements (BTE) from the high-temperature reactor of the Arbeitsgemeinschaft Versuchsreaktor GmbH (AVR) type. The AVR fuel elements are described as consisting of a large number of particles (~20-40k per FE) embedded in a graphite matrix.

The section also describes the loading of the CASTOR® THTR/AVR cask consisting of spherical FE and BTE loaded into two AVR dry storage canisters (AVR-TL canisters) placed one on top of the other inside the cask. Each AVR-TL canister is limited to 960 fuel elements with a cask limit of 1900 fuel elements.

The LLNL Staff concurs that the containment analysis presented considered a maximum loading of 1900 AVR fuel elements per cask, and that the contents are consistent with the document *Type B(U)F Package Transport and Storage Cask CASTOR THTR/AVR Inventory Description.*[9]

Section 3.3 Volumes

This section states that the available cask volume is 648 liters and that the displaced volume of each of the two AVR-TL canisters is approximately 245 liters. Neglecting any free gas volume that may exist inside the AVR-TL canisters for purposes of volume calculations, the cask free volume is taken as 158 liters (=648 liters – 2x245 liters).

The LLNL Staff concurs with the volumes given in the section, and also concurs that taking the minimum free volume yields conservative containment results (i.e., maximum activity concentrations leading to minimum reference air leakage rate).

Section 3.3 Temperatures

This section provides the bounding cavity gas temperature of 346 K for NCT and 412 K for HAC. The average temperature of the cavity gas is taken as the mean value between the cavity wall and the maximum inventory temperature. This approach is conservative since the maximum inventory temperature is reached at the center of a fuel element, which is typically about 10 K hotter than that of the surrounding gas.

The LLNL Staff concurs with the temperatures provided in this section and the methodology for determining the cavity gas temperatures.

Section 3.5 Pressures

This section describes that the CASTOR THTR/AVR cask cavity with the AVR-TL canister is filled with a mixture of Argon and Helium with a total pressure of 130 kPa and a partial Argon pressure of 100 kPa. The AVR-TL canisters are loaded and sealed under an air atmosphere at a pressure of 101.15 kPa. The ideal gas law was used to calculate the pressures inside the cask and in the AVR-TL canisters under both NCT and HAC conditions.

The free volume pressures in the cask are calculated for both NCT and HAC considering two situations: (1) the AVR-TL canisters leak; and (2) the AVR-TL canisters do not leak. Since the pressure in the AVR-TL canisters is always lower than that at the cask free volume outside the AVR-TL canisters, assuming that the cask free volume has the pressure that occurs without AVR-TL canister leakage is conservative. Using this conservative methodology (i.e., the AVR-TL canisters are assumed to not leak, the Maximum Normal Operating Pressure (MNOP) was determined to be 154 kPa, and the maximum cask pressure under HAC was 183 kPa. Note that if leakage is assumed for the AVR-TL canisters, the pressures are lower at 136 and 156 kPa for NCT and HAC, respectively.

The LLNL Staff notes that there is no confinement/containment credit taken for the AVR-TL canisters in the subsequent determination of the releasable source term, only for the conservative determination of maximum pressures for NCT and HAC. The LLNL Staff concurs with the method and results of the MNOP and maximum HAC pressure calculations, and that the determinations of the pressure are conservative (i.e., estimated high).

4. Activity and Gas Mobilization

This section describes that the AVR fuel elements (i.e., AVR-FE), which consist of a large number of particles embedded in a graphite matrix. These particles have coatings of pyrolytic carbon and silicon carbide. These particles are very robust, and mechanically as well as thermally stable. The fuel elements are designed to retain all fission products under reactor conditions with fuel temperatures of 1150^{o}C. The fission products are retained because of the multiple coatings on the particles as well as the carbon coating on the fuel elements. There are more details of the fuel in reference GNB B 329/2003, Revision 0.[9]

Under transport conditions, almost all of the fission products are solids and are bound to the uranium oxide lattice and retained within the coated particles within the fuel elements. Under these conditions, only the release of gaseous krypton (Kr-85) and tritium (H-3) fission products are considered to be released from the fuel elements. Additionally, since the fuel elements have a coating of pyrolytic carbon and there is significant development of activated carbon (i.e., Carbon-14) due to fuel irradiation, the analysis considers reaction of some of this activated carbon with the oxygen in the AVR-TL canisters to form releasable C-14 oxide. Therefore, the releasable source term in the report consists of Tritium, Krypton-85, and Carbon-14 oxide.

The fuel used for the analysis had a burnup of 199 GWd/t and a decay time of 15 years in 2003. The decay of the fuel constituents was calculated using the computer code ORIGEN. The properties of the fuel in 2003 were used for the analysis. For the AVR-FE (Type 2), due to operations in the reactor, the total amount of Tritium generated is 1.1 GBq per fuel element, the total amount of Krypton-85 generated is 5.94 GBq per fuel element; and the total amount of

Carbon-14 generated is 21.3 MBq per fuel element. These activities for the fuel elements were confirmed by the LLNL Staff. The report states that the C-14 is mainly generated through the (n,p) reaction with nitrogen impurities in the graphite matrix and the cooling gas. The analysis in the report relates the amount of C-14 oxide that could form to the amount of oxygen available in a filled AVR-TL container.

In an effort to determine how much of these gaseous radioactive species are available for release (i.e., the releasable source term), measurements were taken on an AVR-TL canister with realistic fuel element loadings. The test system was fitted with valves to allow gas sampling and was in a 30^{o}C storage environment.[10,11] From these measurements it was found that the Kr-85 activity in the test container did not increase above 15 MBq. It is expected that the tritium is in the form of tritiated water (HTO) which would mostly be bound to the inner container surface and not be available for release until the container was opened, where up to 50-times the original activity present can become mobilized. Therefore, since there are two-times more tritium produced than Kr-85, for an opened AVR-TL container, it is expected that there are 1.5 GBq as HTO contributing to the releasable source term in the cask atmosphere. If the C-14 can react with the oxygen available in the AVR-TL canisters to form releasable C14 oxide, the amount of C-14 oxide per AVR-TL canister is 45 MBq.

Therefore, a summary of the calculated total Tritium, Kr-85, and C-14 inventory per cask (i.e., total of 1900 fuel elements per cask), as well as the releasable portion determined by measurement (and the resulting release fraction) are given below:

Nuclide	**Activity/Fuel Element**	**Total Activity/Cask**	**Releasable Activity/Cask**	**Release Fraction**
H-3	1.1 GBq	2.1 TBq (565.5 Ci)	3.0 GBq	1.4×10^{-3}
C-14	21.3 MBq	0.04 TBq (1.1 Ci)	0.1 GBq	2.5×10^{-3}
Kr-85	5.94 GBq	11.2 TBq (305.0 Ci)	0.03 GBq	2.7×10^{-6}

Using these values for the releasable source term, the effective A_2 of the releasable source term is determined to be A_2=28.8 TBq. With a cask void volume of 158 liters, the activity concentration of the releasable source term is calculated as 19.8 GBq/m^3.

The LLNL Staff confirmed the structure and performance of the fuel, namely that the particulate fuel and fission products are not expected to be released from the fuel into the package void volume under transport conditions. The LLNL Staff also confirmed that the values for the A_2 and the activity concentration of the releasable source term are correct. It should be noted that the review and confirmatory analyses by the LLNL Staff are based on the values in Table 3 of the document, and that the value of 0.3 MBq in the text (page 11) for the Kr-85 mobilized appears to be in error (should be 30 MBq).

5. Leakage Rate Acceptance Criteria

5.1 Calculation Model

This section describes that combined viscous and molecular flow equations were used to calculate the flow of a gaseous substance through a circular capillary. The LLNL Staff confirmed that the equations used for leakage flow calculations are consistent with those in ANSI N14.5-2014.

5.2 Allowable Leakage Rate

Since the allowable leakage rate is the ratio of the allowable activity release rate to the releasable activity concentration. For NCT, the allowable activity release rate is $R_N=10^{-6}$ A_2/hr, and for HAC, $R_A=A_2$/week. Using the effective A_2 value of 28.8 TBq and the activity concentrations of $C_N=C_A=19.8$ GBq/m^3 results in allowable leakage rates of $L_N=4.0\times10^{-7}$ m^3/s for NCT, and $L_A=2.4\times10^{-3}$ m^3/s for HAC.

The LLNL Staff have performed confirmatory calculations and concur with the equations given for the allowable release rates, the calculated effective A_2, the calculated activity concentrations, and the calculated allowable leakage rates for NCT and HAC.

5.3 Capillary Diameter

The equivalent capillary diameter is calculated using the Knudsen equation for both L_A and L_N using the relevant parameters, as listed in the following table:

Parameter	NCT	HAC
Gasket Temperature, K	330	472
Upstream Pressure, Pa	1.5x10^5	1.8 x10^5
Downstream Pressure, Pd	2.5 x10^4	1.0 x10^5
Allowable Leakage Rate, m^3/s	4 x10^{-7}	2.4 x10^{-3}
Gas	Helium	
Molar Mass, Kg/mol	4x10^{-3}	
Viscosity, Pa.s	2.1 x10^{-5}	2.7 x10^{-5}
Capillary Length, m	3.5 x10^{-3}	
Calculated Allowable Capillary Diameter, m	6.2 x10^{-5}	6.2 x10^{-4}

The LLNL Staff concurs with the input values and the calculated allowable capillary diameters given in the able table.

5.4 Reference Air Leakage Rates

Using the smaller capillary diameter, which is from the NCT calculation, along with P_u=1 atm, P_d=0.01 atm, gas is dry air, molar mass is 28.9 g/mol, gas viscosity is 0.0183, and the capillary length is 3.5x 10^{-3} m, the reference air leakage rate is calculated as 0.3 ref·cm^3/s. The LLNL Staff concur with this reference air leakage rate.

This section also includes a conservative calculation where all retention mechanisms are neglected for the three nuclides that form the releasable source term are fully mobilized. For this case, the report lists an activity concentration of 85 TBq/m^3 and an effective A_2 of 75.1 TBq. Using these values along with the parameters listed above, the allowable volumetric leakage rates of $2.5x10^{-10}$ m^3/s for NCT and $1.5x10^{-6}$ m^3/s for HAC, and the resulting reference air leakage rate of $1.7x10^{-4}$ $ref{\cdot}cm^3/s$.

The LLNL Staff concurs with the 0.3 $ref{\cdot}cm^3/s$ reference air leakage rate result, and also concurs that for the case where all retention mechanisms were neglected that the activity concentration is 85 TBq/m^3, and effective A_2 is 75.1 TBq, and the resulting reference air leakage rate is $1.7x10^{-4}$ $ref{\cdot}cm^3/s$.

6 Conclusions

The conclusion states that the containment criteria for AVR inventories in the CASTOR® THTR/AVR are satisfied if the containment system does not exceed a maximum admissible reference air leakage rate of 0.3 $ref{\cdot}cm^3/s$ (corresponds to a standard helium leakage rate of 0.29 $std{\cdot}cm^3/s$). It is stated that the reference air leakage rate has to be proven for each package, and the leak-tightness of the lid sealing system of a loaded CASTOR® THTR/AVR is tested prior to transport using a specific helium leak tightness test procedure. The conclusion also notes that the test criterion for the leak-tightness testing prior to transport is defined to also cover the requirements that would result from neglecting all retention mechanisms for H-3, Kr-85, and C-14, i. e. a reference air leakage rate of $L_R = 1.7x10^{-4}$ $ref{\cdot}cm^3/s$.

The conclusion stipulates that ‘The leak-tightness of the cask's structural components including the cask body, the secondary lid, the blind flange and the protection cap are verified on original packaging components of an empty and contamination-free serial sample using another helium leak-tightness test procedure,’ also that ‘In this way, compliance with the admissible standard helium leakage rate for the entire containment system can be demonstrated.’

The LLNL Staff concludes that the it is intended that prior to transport all loaded CASTOR® THTR/AVR casks will demonstrate a leakage rate to a sensitivity of less than or equal to $1.7x10^{-4}$ $ref{\cdot}cm^3/s$ using the combined leakage rate of the primary lid from the pre-shipment leakage test along with the leakage rate test of the remainder of the body conducted on a serial sample with the procedure PV 360/82, Revision 1. In fact, the leakage test implementing procedure, PV 360/82, Revision 1, has a leakage test acceptance criteria of $9x10^{-8}$ $pa{\cdot}m^3/s$ (or $8.9x10^{-7}$ $atm{\cdot}cm^3/s$) for the containment boundary of the cask excluding the primary lid. This acceptance criterion for the cask containment system satisfies the determined package reference leakage rate criterion of 0.3 $ref{\cdot}cm^3/s$, and also the leakage criteria of $1.7x10^{-4}$ $ref{\cdot}cm^3/s$ that corresponds to the very conservative case of no retention mechanisms for H-3, Kr-85 and C-14 oxide.

However, the LLNL Staff concludes that the approach intended to demonstrate the leak-tightness of the portions of cask's containment system other than the lid sealing system using ‘original packaging components of an empty and contamination-free serial sample’ is not completely consistent with ANSI N14.5-2014. Section 7.3 Fabrication Leakage Rate Test of ANSI N14.5-2014, which states that the entire containment boundary, including base material, welds, seals, closures, valves, rupture disks, or other boundary elements shall be tested, and that this fabrication leakage rate testing shall be performed prior to first use of each packaging.

The LLNL Staff understands that many if not all of the loaded CASTOR® THTR/AVR casks currently in storage in Julich did not undergo a fabrication leakage test of the entire containment boundary prior to first use. The LLNL Staff understands that the approach of performing a leakage test on the lid sealing system of each package prior to transport combined with the leakage testing on the remaining portions of the cask's containment boundary using an empty contamination-free serial sample is intended to supply sufficient confidence that the fabrication leakage rate test as described in ANSI N14-5-2014 is satisfied. The LLNL Staff cannot ensure that this approach with be satisfactory to the Nuclear Regulatory Commission. It is recommended that the term *serial sample* be defined and described in detail including to identify the number, type, and specifics of the serial samples to be used to complete the pre-shipment leakage test requirements for the packages intended for shipment.

The following are the results of review of *Test Specification Cask Structural Component – Leak tightness test Helium leak-tightness test procedure – CASTOR® THTR/AVR*, PV 360/82, February 14, 2019, Revision 3.

The LLNL Staff has reviewed the implementing procedure for leakage testing of the cask body components and found the procedure, including the equipment, equipment arrangements, and process steps, to be adequate for demonstrating the leakage rate criteria specified for the various packaging components.

4.0 LLNL Staff's Conclusions

The LLNL Staff has reviewed Revision 1 of the containment analysis for the CASTOR® THTR/AVR with the approved AVR contents. The LLNL Staff concurs with the description of the containment boundary of the CASTOR® THTR/AVR Package, and the approved AVR contents loading (i.e., maximum loading of 1900 AVR fuel elements per cask). The LLNL Staff confirmed the structure and performance of the fuel elements, namely that the particulate fuel and fission products are not expected to be released from the fuel into the package void volume under transport conditions. The LLNL Staff confirmed the isotopes present in the fuel for the listed initial enrichment, burnup, and cooling time. The LLNL Staff concur that the releasable nuclides (i.e., the nuclides that can escape the fuel elements and constitute the releasable source term in the cask) include H-3 and Kr-85, and C-14 oxide. The LLNL Staff notes that the applicant assumed that the releasable C-14 was in the form of an oxide formed by reaction with the oxygen in the AVR-TL canisters.

The LLNL Staff concurs with the cask free volume determinations, and that taking the minimum free volume yields conservative containment results (i.e., minimum reference air leakage rate). The LLNL Staff concurs with the bounding temperatures provided and the methodology for determining the cavity gas temperatures.

The LLNL Staff notes that there is no confinement/containment credit taken for the AVR-TL canisters in the determination of the releasable source term, only for the conservative determination of maximum pressures for NCT and HAC. The LLNL Staff concurs with the method and results for determining the MNOP and maximum HAC pressure, and that the determinations of the pressure are conservative (i.e., estimated high). The LLNL Staff notes that helium is conservatively used as the gas in the containment analysis although the realistic case would be a mixture of helium and air.

The LLNL Staff confirmed that the containment analysis calculational approach was consistent with NUREG/CR-6487 and ANSI N14.5. Also, the LLNL Staff concur with the equations used and the results given for the allowable release rates, the calculated effective A_2, the calculated activity concentrations, and the calculated allowable leakage rates for NCT and HAC. The LLNL Staff notes that the allowable leakage rate for NCT is also conservative due to the significant reduction in the assumed external pressure of 0.25 atm.

The LLNL Staff concurs with the determined 0.3 ref·cm^3/s reference air leakage rate when using the experimentally-derived releasable source term results. The LLNL Staff notes that the conservatism of the experimentally-derived results may be questioned since the experiments were apparently conducted without consideration of transportation-induced forces (e.g., vibrations or shocks). It is recommended that the applicant be prepared to discuss the possible influence of vibration or shocks on the release fractions for H-3, Kr-85 and C-14.
The LLNL Staff also concurs with the determined reference air leakage rate of 1.7×10^{-4} ref·cm^3/s when using the very conservative approach of neglecting retention mechanisms for the three releasable source term nuclides (i.e., H-3, Kr-85, and C-14).

It should be noted that the foregoing are the conclusions and recommendations of the LLNL Staff and do not propose to indicate the expectations of the NRC.

5.0 References

[1] *Containment Analysis for the Type B(U)F Package Transport and Storage Cask CASTOR® THTR/AVR*, GNS B 325/2018, Revision 1, June 26, 2020.

[2] *CASTOR® THTR/AVR Approval Certificate*, D/4214/B(U)F-96, Revision 11, February 17, 2017.

[3] *Packaging and Transportation of Radioactive Material*, Title 10 of United States Code of Federal Regulations, Part 71.

[4] *Test Specification Cask Structural Component – Leak tightness Test Helium leak-tightness test procedure – CASTOR® THTR/AVR*, PV 360/82, Revision 1, June 24, 2020.

[5] *Containment Analysis for Type B Packages Used to Transport Various Contents, United States Nuclear Regulatory Commission*, NUREG/CR-6487, October 1996.

[6] *Standard Review Plan for Transportation Packages for Spent Nuclear Fuel, United States Nuclear Regulatory Commission*, NUREG-1617, March 2000.

[7] *American National Standard for Radioactive Materials - Leakage Tests on Packages for Shipment*, American National Standards Institute, ANSI N14.5-2014.

[8] *Type B(U)F Package Transport and Storage Cask CASTOR® THTR/AVR Safety Verification*, GNB B 078/2004, Revision 0, May 18, 2004.

[9] *Type B(U)F Package Transport and Storage Cask CASTOR® THTR/AVR Description of Inventory*, GNB B 329/2003, Revision 0, May 14, 2004.

[10] *Status Seminar / High-Temperature Reactor Fuel Cycle, Lectures on work in the fields of HTR fuel assembly development, HTR Graphite development, and HTR disposal,* Nuclear Research Facility Jülich GmbH, Julich, May 1987.

[11] *C-14 Inventory and Release of Fuel Assemblies in Dry Storage Canisters*, Nuclear Research Facility Jülich GmbH, Technical Note 27.05.IRW - TN - 40/88 en 1988, May 27, 1988.